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(54) Method of plant culture

(57) Plant growth is influenced by placing the plants at an electrical potential different from natural or ambient potential. This may be applied to the container or a lining therefor in which the plants are grown, and/or to a lightweight element spread over the growing plants. Different effects are obtainable by the timing of the potential appliance: it may be continuous or for periods during the day or night. The light for the plant may be daylight or artificial, and when natural daylight is used it could be artificially extended. In most cases stimulation of growth is achieved, but in some circumstances it is possible to retard.

GB 2 210 765 A

Method of Plant Culture

This invention relates to a method of plant culture in which some or all of the plant material is deliberately placed at an electrical potential different from the ambient potential, with the specific aim of enhancing plant growth and productivity through an electrostatic charge influence on the photoperiodic response mechanism. Interaction with other plant growth control mechanism is also possible.

For many purposes it is customary to regard the electrical potential of the Earth's surface as zero, but in practice there exists in the upper atmosphere (at a height of about 50 km) an electrically charged layer known as the 'electrosphere' which is characterised by possessing an average potential of  $2.9 \times 10^6$  V positive with respect to the Earth. The electrosphere and the Earth can be regarded as the two conducting plates of a spherical condenser system, with the lower atmosphere acting as an (imperfect) dielectric, across which an electrical potential gradient therefore exists. As a consequence, in fine weather clear sky conditions, the Earth carries a negative bound surface charge. This can be reversed in polarity and substantially increased in magnitude by the approach of an electrically charged cloud - for example a thunder cloud. Detailed

consideration of these and other aspects is given in a standard reference book by J. A. Chalmers, "Atmospheric Electricity", Pergamon, Oxford (2nd Edition 1967).

For atmospheric electrical considerations it is often convenient to define the Earth's surface in a broad sense and to include therein the terrestrial vegetation mantle, both natural and cultivated, since a plant growing in the open soil comprises an electrical extension of the Earth, and the plant surface will then effectively constitute the interface between the variably conducting Earth-vegetation complex and the atmospheric dielectric and will accordingly participate in interfacial charge accumulation and transfer processes.

Plant surface potential changes may also result from the impaction of charged precipitation particles.

Under natural conditions therefore, plants are subject to definite, although variable, imposed electrical potentials characterised by the existence of a quantifiable excess of positive or negative charge. It is the physiological significance of these and similar artificial charges which, in part, forms the basis of the present invention.

The existence and possible physiological significance of natural electric currents in higher plants are well documented: for example by L. F. Jaffe

and R. Nuccitelli, Ann. Rev. Biophys. Bioeng., 6 445 -  
476 (1977); M.H. Wiersenseel et al; Plant Physiol., 64  
512-518 (1979) and D.J.F. Bowling et al., J. Exp. Bot.,  
37 876-882 (1986). Various plant physiological  
5 processes thought to be associated with electrical  
charge changes in plants are known to be susceptible to  
influence by the external environment. For example  
D.J.F. Bowling et al., (cited above) observed that  
artificially changing the pH of the solution bathing a  
10 plant leaf under laboratory conditions could alter the  
magnitude of the natural electric current detectable  
with a vibrating probe electrode at the plant surface.

Many aspects of plant development are influenced by  
changes in the duration and spectral composition of  
15 ambient light. Such changes are known to be detected  
through one or more photoreceptor systems, of which the  
most widely studied is that dependent on the reversible  
photochemical transformation of phytochrome.  
Phototransformation of this effector substance is known  
20 to proceed through several intermediate stages, at least  
some of which are 'strongly influenced by the molecular  
environment' as reported by R.E. Kendrick and C.J.P.  
Spruit in "Light and Plant Development", ed. H. Smith,  
Butterworth, London (1976) p 40-41.

25 It is this environmental sensitivity, as influenced  
by the ambient ionic milieu, itself modulated by

external applied potentials, which, in part, forms the basis of the present invention, although interaction with other, currently less well understood, plant growth control mechanisms is also possible.

5        For more than 200 years there has been speculation on the possible role of atmospheric electricity in controlling plant growth and development, but little attention has previously been directed to links with plant photoperiodism. Partial reviews have been made by  
10    G. H. Sidaway, J. Electrostatics, I 389-393 (1975) and by H.W. Ellis and E.R. Turner, Science Progress, Oxford, 65 395-407 (1978). Literature papers concerned with natural electric currents in plants, and the application of electrical potentials to plants, have been reviewed  
15    by L.F. Jaffe and R. Nuccitelli (cited above) and discussed by A. Goldsworthy and K.S. Rathore in patent specification GB2,149,818A.

      L.S. Wachter and R.E. Widmer, HortScience II 576-578 (1976), reported air ionization experiments with plants  
20    in which a distinction was made between treatment during the day and during the night. A paper by F.M. Yamaguchi, Soilless Culture, I 35-53 (1985) also reported an experiment in which differences were noted in the response of tomato plants to air ionization during the  
25    day and during the night. Specific electrical interactions with daylength were not proposed however.

Artificial air ionization techniques to increase plant growth have been advocated by various workers as discussed for example in a paper by T.M. Elkies et al., Int. J. Biometeor., 29 285-292 (1985). Many recent  
5 investigators in this field have broadly accepted the postulate of A.P. Krueger et al., Nature, 200 707-708 (1963), that air ions increase the biosynthesis of iron-containing enzymes, particularly cytochrome c. It has  
10 been generally assumed, however, that plant growth responses to environmental electricity can be interpreted in some way in terms of specific air ion activity, or current flow through the plant, while effects of the associated surface charge density have been largely ignored.

15 Considerations of plant physiology have traditionally been applied to situations where the plant material was not at an electrical potential significantly different from that of its surroundings, and it is a basic principle of plant/soil relationships  
20 for example, that overall electrochemical neutrality should be maintained during nutrient ion uptake from the soil: as clearly stated by E. A. Kirby in "Ecological Aspects of the Mineral Nutrition of Plants", ed. I.H. Rorison, Blackwell, Oxford (1969) p.215. What may be  
25 termed the 'concept of non-electroneutrality' appears totally foreign to conventional plant physiological

thought, and its consequences therefore have attracted no attention in the literature.

In a recent paper, M. Montavon et al., Ann. Bot., 60  
225-230 (1987), reported that passing electrical  
5 currents of  $12.5\mu\text{A}$  at 10 V through a petiole, or between  
a petiole and the roots, of spinach plants, induced  
changes in the plant's response to different  
photoperiodic regimes. The technique used, however, was  
clearly intended to bring about the passage of an  
10 electric current through the plant, and the author's  
published interpretation of their results did not  
include any reference to the possibility of a specific  
electrical interaction with the phytochrome system.

In summary, the present applicants are not aware of  
15 any previous claims that manipulation of the ambient  
electrical environment by artificially generated low  
voltage static potentials can be used to influence plant  
growth and development through an assumed interaction  
with the photoperiodic, or other, control systems.

20 According to the present invention there is provided  
as method of influencing plant growth, wherein the plant  
is placed at an electrical potential different from the  
natural or ambient potential.

It is believed that such environmental electrical  
25 modification will induce local electric charge  
concentration imbalances within the plant and since the

plant is an ionic conductor, such charge imbalances may effectively translate environmental electrical influences into biochemical influences which could be of economic significance.

5       The plant may be grown in a container to which the potential is applied, or in a container which is not electrically conductive but which has a conductive lining to which the potential is applied. Alternatively, or in addition, it may be arranged to grow up against a  
10   lightweight, electrically conductive element to which the potential is applied, such as a film, foil or net. Where there are two or more electrodes, they will be at the same potential. Using the container is probably simpler, as it avoids the light shielding problem of a  
15   film or foil or the possible entanglement with a net. The container may be of almost any form, such as a plant pot, a solid or open-based seedling tray, or a tree shelter. When plastic or other non-conductive containers may are used the conductor lining will conveniently be a  
20   metallic foil, for example, coupled to the potential source.

      The potential may be applied continuously or intermittently, and when not continuous it is preferred that it should be done so mostly, at least, during the  
25   hours of darkness, particularly over an early period of such hours. The useful and safe range is considered to

be 12V - 100V.

Generally, for improved growth it will be better to apply a positive potential, but this factor, and the others such as timing and potential level can be expected to be different for optimum response of different plants and culture systems.

For a better understanding of the invention, some examples are given below of various comparative studies.

Example 1..

10       Seeds of French Bean, Phaseolus vulgaris cv Blue Lake (obtained from Suttons Seeds Ltd., Torquay, Devon, U.K.) were sown 2 cm deep in a peat based compost in individual 8 cm plastic flower pots and grown in the dark at 28°C for three days, by which time germination  
15       had occurred and the hypocotyl hooks were just emerging through the soil surface. Uniform seedlings were selected and placed in plastic trays, lined with electrically conducting material. Some linings remained uncharged while others were linked to a DC power supply  
20       unit providing 45 V positive or negative for 8 hours per day as indicated below. The plants were then grown in natural daylight in a greenhouse with a minimum night temperature of 15°C and a maximum day temperature of 25°C.

25       After 11 days with electrical treatment during the first half of each 16 hour night, the primary leaf areas

per plant were as follows:

Positive charge	$75.46 \pm 4.34 \text{ cm}^2$
Uncharged	$64.77 \pm 4.34 \text{ cm}^2$
Negative charge	$70.60 \pm 4.34 \text{ cm}^2$

5 For  $p = 0.05$ ,  $\text{lsd} = 12.59 \text{ cm}^2$ .

Where  $p$  is 'probability' and  $\text{lsd}$  is 'least significant difference.'

At this time the cotyledons were falling, and the epicotyl lengths were as follows:

10	Positive charge	$35.50 \pm 1.88 \text{ mm}$
	Uncharged	$36.80 \pm 1.88 \text{ mm}$
	Negative charge	$37.80 \pm 1.88 \text{ mm}$

For  $p = 0.05$ ,  $\text{lsd} = 5.45 \text{ mm}$

15 Four days later all cotyledons had fallen, and the combined lengths of the first two internodes (above the epicotyl) were as follows:

Positive charge	$85.80 \pm 6.68 \text{ mm}$
Uncharged	$68.40 \pm 5.68 \text{ mm}$
Negative charge	$80.67 \pm 5.98 \text{ mm}$

20 For  $p = 0.05$ ,  $\text{lsd} = 16.50 \text{ mm}$

In a further experiment on similar plant material with similar preparation electrical treatment was given during the second half of each 16 hour night. The primary leaf areas per plant at 11 days were:

25	Positive charge	$77.41 \pm 4.08 \text{ cm}^2$
	Uncharged	$65.56 \pm 4.08 \text{ cm}^2$

Negative charge  $70.51 \pm 4.08 \text{ cm}^2$

for  $p = 0.05$ ,  $\text{lsd} = 11.83 \text{ cm}^2$

and epicotyl lengths were

Positive charge  $39.40 \pm 1.72 \text{ mm}$

5      Uncharged  $34.90 \pm 1.72 \text{ mm}$

Negative charge  $30.50 \pm 1.72 \text{ mm}$

For  $p = 0.05$ ,  $\text{lsd} = 4.99 \text{ mm}$

For  $p = 0.002$ ,  $\text{lsd} = 8.34 \text{ mm}$ .

10      After a further four days growth. under the same  
conditions, the combined lengths of the first two  
internodes were:

Positive charge  $94.90 \pm 7.50 \text{ mm}$

Uncharged  $77.90 \pm 7.50 \text{ mm}$

Negative charge  $82.10 \pm 7.50 \text{ mm}$

15      For  $p = 0.05$ ,  $\text{lsd} = 21.77 \text{ mm}$

### Example 2

In the two experiments just described, daylength was  
controlled artificially. The two following experiments,  
using the same plant material, were carried out with  
20      continuous electrical treatment (24 hour day) at 24 V  
potential in natural daylengths in early summer  
(Cardiff:  $51^\circ 32'$  N latitude).

In the first experiment the mean combined lengths of  
the first 3 internodes after 14 days treatment starting  
25      on 26 April were:

Positive charge  $178.0 \pm 17.9 \text{ mm}$

Uncharged 151.4  $\pm$  17.9 mm

Negative charge 210.6  $\pm$  17.9 mm

For p = 0.05, lsd = 52.3 mm

5 In the second experiment, the mean combined lengths of the first 4 internodes after 20 days treatment starting on 15th May, were:

Positive charge 403.3  $\pm$  48.3 mm

Uncharged 357.4  $\pm$  48.3 mm

Negative charge 516.6  $\pm$  50.9 mm

10 For p = 0.05, lsd = 144.3 mm

Total primary leaf areas per plant in the first experiment were:

Positive charge 111.7  $\pm$  8.2 cm<sup>2</sup>

Uncharged 108.3  $\pm$  8.2 cm<sup>2</sup>

15 Negative charge 124.0  $\pm$  8.2 cm<sup>2</sup>

and in the second experiment:

Positive charge 135.7  $\pm$  6.7 cm<sup>2</sup>

Uncharged 127.2  $\pm$  6.7 cm<sup>2</sup>

Negative charge 142.7  $\pm$  7.1 cm<sup>2</sup>

20 In this experiment, total areas were also determined for the second leaf (i.e. the first trifoliate leaf) as follows:

Positive charge 33.9  $\pm$  3.3 cm<sup>2</sup>

Uncharged 29.0  $\pm$  3.3 cm<sup>2</sup>

25 Negative charge 39.7  $\pm$  3.4 cm<sup>2</sup>

For p = 0.05, lsd = 9.8 cm<sup>2</sup>

Example 3

Different responses to electrical treatment at different times of day would be expected if the electrical influence interacts with endogenous rhythms. Some indication of this is provided by the following examples using the 'Japanese Morning Glory', Pharbitis nil cv Violet (obtained from Marutane Co. Ltd., Shichijodori Shinmachi, Kyoto, Japan). Unless otherwise stated all cultural procedures with this plant were carried out at a temperature of 25°C in continuous illumination from six 150 cm 65 W white fluorescent lamps mounted 60 cm above the culture benches.

To obtain uniform germination, the hard seed coats were carefully chipped with a sharp blade and seeds were then immersed in tap water for 12 hours before being spread on a layer of damp compost while cotyledon expansion occurred. Uniform seedlings were then potted singly in 8 cm plastic flower pots, before receiving a single dark treatment (to induce flowering) with associated electrical treatment at the times shown.

In the first experiment the plant pots were placed in plastic trays lined with conducting foil and were covered with lightweight foil electrodes resting directly on the expanded cotyledons. The plants were immediately placed in darkness for 16 hours with a 12 V DC potential applied to the foil (the upper and lower

foils in each tray being at the same potential) for the first 8 hours of darkness only. This treatment started 115 hours after the chipped seeds were immersed in water.

5        12 days later the mean plant heights were as follows:

Positive charge         $284.0 \pm 19.0$  mm

Uncharged               $157.9 \pm 19.0$  mm

Negative charge         $272.2 \pm 19.0$  mm

10       For  $p = 0.001$ ,  $lsd = 99.2$  mm

As a measure of floral development, the combined lengths of all flower buds were determined for each plant, giving the following mean values:

Positive charge         $36.7 \pm 2.1$  mm

15       Uncharged               $24.4 \pm 2.1$  mm

Negative charge         $43.2 \pm 2.1$  mm

For  $p = 0.001$ ,  $lsd = 11.1$  mm

In a second experiment of this Example, the same type of plants with similar preparation were given a 12  
20 hour dark treatment with a 24 V charge throughout this period which started 122 hours after the commencement of seed imbibition. 17 days later mean plant heights were as follows:

Positive charge         $398.3 \pm 37.5$  mm

25       Uncharged               $460.7 \pm 37.5$  mm

Negative charge         $329.3 \pm 37.5$  mm

For  $p = 0.02$ ,  $lsd = 131.1$  mm

and mean flower bud lengths were:

	Positive charge	$42.1 \pm 4.2$ mm
	Uncharged	$49.6 \pm 4.2$ mm
5	Negative charge	$54.2 \pm 4.2$ mm

For  $p = 0.05$ ,  $lsd = 12.1$  mm

In the third experiment of this Example, with similar plant material and preparation, treatment commenced 164 hours after the start of seed imbibition, and comprised a 16 hour dark period with 24 V potential applied during the first 8 hours of darkness only. 16 days later mean plant heights were as follows:

	Positive charge	$338.6 \pm 34.2$ mm
	Uncharged	$366.0 \pm 34.2$ mm
15	Negative charge	$275.4 \pm 34.2$ mm

and mean flower bud lengths:

	Positive charge	$22.1 \pm 3.5$ mm
	Uncharged	$14.0 \pm 3.5$ mm
	Negative charge	$28.1 \pm 3.5$ mm

For  $p = 0.02$ ,  $lsd = 12.7$ mm

For  $p = 0.01$ ,  $lsd = 14.3$  mm

Although of limited statistical value, two other experiments are of interest as indicators of the wider appeal of this technique.

#### 25 Example 4

A small number of plants of Hypoestes sanguinolenta,

a popular foliage houseplant, were grown in electrically charged trays for 8 weeks at 50 cm below three 25 W tungsten filament light bulbs giving 16 hour daylengths. A 24 V charge was applied to the plant trays during the light period only, as a preliminary test for a possible electrical action on photomorphogenic activity during light exposure. Tungsten filament light sources emit radiation relatively rich in the near infra-red wavelengths which are known to be conducive to stem elongation in many plants.

Increases in plant height over the 8 week period were:

Positive charge	10.0 $\pm$ 5.6 mm
Uncharged	21.0 $\pm$ 5.6 mm
Negative charge	20.0 $\pm$ 5.6 mm

Thus the charges, particularly the positive one, retarded growth. While that may not be a usual requirement, it may in certain circumstances or for certain effects be desired.

#### 20 Example 5

To assess the possibility that electrical treatment could partially substitute for the cold requirement in spring flowering bulbs, a quantity of Dutch grown Darwin Hybrid Tulips 'Golden Apeldoorn' were obtained in early October from a local retail outlet and some of the dry bulbs were placed in externally insulated but

internally electrically conducting envelopes at potentials of 100 V  $\pm$  above ground continuously for 35 days. A 'control' batch of bulbs was stored in identical envelopes but uncharged. All bulbs were stored in darkness at normal humidity in a temperature range between 10°C and 20°C. After this pretreatment the bulbs were planted in peat based compost and grown in a greenhouse with a 15°C - 20°C temperature range. Potentials of 80 V  $\pm$  (or 0 V) were applied to the appropriate plants for 8 hours during the night. After 3 weeks, bulbs were examined and shoot growth determined as follows:

	Positive charge	16.0 $\pm$ 2.0 mm
	Uncharged	9.2 $\pm$ 2.0 mm
15	Negative charge	10.6 $\pm$ 2.0 mm
	For p = 0.05, lsd = 6.1 mm	

Bulbs which had not been electrically pre-treated did not show this variation in growth.

As well as using this technique on relatively small plants, in a greenhouse or other controlled environment, it is envisaged that it will also be applicable to larger "outdoor" plants such as shrubs and trees.

It will be seen from the above that the response to a particular electric charge treatment may vary both at different stages of plant development and at different times of application during the day or night. Indeed the

same polarity of charge may produce an acceleration or a retardation of growth depending on the timing of electrical treatment. Generally, potentials of less than 12 V are not expected to influence growth significantly, at least if applied only to the plant container, because of the voltage drop due to resistance within the plant. Potentials of above 100 V may be considered somewhat hazardous for normal use even with appropriate short circuit safety fusing.

CLAIMS

1. A method of influencing plant growth, wherein the plant is placed at an electrical potential different from the natural or ambient potential.

2. A method as claimed in Claim 1, wherein the  
5 plant is grown in a container to which the potential is applied.

3. A method as claimed in Claim 1, wherein the plant is grown in a container which is not electrically conductive but which has a conductive lining to which  
10 the potential is applied.

4. A method as claimed in Claims 1 2 or 3, wherein the plant is grown up against a light, electrically conductive element to which the potential is applied.

5. A method as claimed in Claim 4, wherein the  
15 conductive element is a film, foil or net.

6. A method as claimed in any preceding claim, wherein the potential is applied continuously.

7. A method as claimed in any preceding claim, wherein the potential is applied intermittently.

8. A method as claimed in Claim 7, wherein the  
20 potential is applied mostly, at least, during hours of darkness.

9. A method as claimed in Claim 8, wherein the potential is applied over an early period of the hours

of darkness.

10. A method as claimed in any preceding claim wherein the potential is in the range 12 V - 100 V.